

RELATION OF TEMPERATURE OF FERMENTATION TO QUALITY OF SAUERKRAUT¹

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INTRODUCTION

The importance of temperature control in sauerkraut manufacture is becoming better appreciated in factory practice, but until now only cursory observations, rather than accurate measurements under well-regulated conditions, have been made. Since the temperature of cabbage as it comes into the factory may vary from as high as 85° to as low as 32° F., depending upon weather conditions, temperature control has been adopted in many factories. Great differences of opinion exist among sauerkraut packers, however, as to the best temperature at which to carry out the fermentation. Some prefer to operate at a temperature of 70° to 80°, while others let the temperature fall as low as 50°. The higher temperature has the advantage of inducing a rapid formation of acid, but this is offset by a tendency to produce soft and pink sauerkraut. For this reason a temperature must be selected which gives a rapid fermentation without sacrificing the quality of the product.

REVIEW OF LITERATURE

The literature on the relation of temperature to sauerkraut fermentation is both meager and conflicting. Wehmer³ recommends a temperature of 40° F. Henneberg⁴ suggests that 68° to 77° be employed at the start and 50° to 59° during the later stages of the fermentation. Fabian⁵ recommends that the fermentation be carried out at 80° in order to give a product of pleasant taste and aroma. LeFevre⁶ reports that sauerkraut can be made in from six to eight days by employing a temperature of 80°. The present authors have never been able to make sauerkraut of good quality at this temperature. It was possible to obtain a sufficiently high acid concentration in a short time at this temperature, but the product still possessed the characteristic odor and flavor of raw, sour cabbage rather than that of sauerkraut. At elevated temperatures (75° to 80°) there is also serious danger of producing soft and slimy sauerkraut and at times pink sauerkraut. In a previous study of the relation

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³ WEHMER, C. DIE SAUERKRAUTGÄRUNG. *Centbl. Bakt. [etc.]* (II)10: [625]-629. 1903.

⁴ HENNEBERG, W. DAS SAUERKRAUT (SAUERKOHLE). 89 p. illus. *Inst. Gärungsgewerbe*, Berlin. 1916. [Reprint from *Deut. Essigindustrie Jahrg.* 20: [133]-136, [141]-144, 152-155, 160-161, 166-170, 176-177, 184-185, 192-194, 199-202, 207-209, 215-216, 223-225, illus. 1916.]

⁵ FABIAN, F. W. THE SCIENCE OF MAKING SAUERKRAUT. CARE NEEDED TO EXCLUDE UNDESIRABLE BACTERIA FROM KRAUT—HOME-MADE STARTER MAY BE USED. *Mich. Agr. Expt. Sta. Quart. Bul.* 9: 50-51. 1926. [Also *Market Growers' Jour.* 41: 639. 1927.]

⁶ LEFEVRE, E. THE COMMERCIAL PRODUCTION OF SAUERKRAUT. *U. S. Dept. Agr. Circ.* 35, 30 p., illus. 1928.

of temperatures to commercial sauerkraut production, it was reported ⁷ that the best sauerkraut was produced when temperatures between 55° and 65° existed in the vat. The experiments recorded in this paper are a continuation and extension of the previous work, and the results now presented substantially confirm it as to the best temperatures at which to produce sauerkraut.

EXPERIMENTAL METHODS

LABORATORY EXPERIMENTS

The sauerkraut was made either in 10-gallon stone jars or in 45-gallon barrels. Early Copenhagen and All Seasons cabbage were used. Sixty pounds of cabbage were packed in the jars and 300 pounds in the barrels. Two and one-half per cent of salt was used in all cases. The following three ranges of temperature were studied: -10° to 50°, 55° to 60°, and 70° F.

The fermentations at 70° F. were carried out in a greenhouse where the temperature was maintained by means of thermostat control. The fermentations at 55° to 60° were conducted in a basement, the temperature being regulated by means of steam heat and air circulation. The low-temperature fermentations, -10° to 50°, were made in barrels placed outside of the building where they remained from December to March.

TABLE 1.—*The effect of fermentation temperature on the quality of sauerkraut*

Sample No.	Size of container	Temperature of fermentation	Age of sauerkraut	Final acidity as lactic acid	Quality
		° F.	Days	Per cent	
1	10-gallon jar	60	43	1.98	Good.
2	do	60	43	1.92	Do.
3	do	70	43	2.02	Fair.
4	do	70	43	1.91	Do.
5	45-gallon barrel	-10 to 50	125	.58	Very poor.
6	do	-10 to 50	125	.58	Do.
7	do	55 to 60	35	1.67	Good.
8	do	55 to 60	35	1.72	Do.
9	do	70	35	1.62	Poor.
10	do	70	35	1.62	Do.

Table 1 summarizes the results of the experiments. The sauerkraut made at 70° F. was only fair in quality; that which was made at 55° to 60° was good in every instance, and that which stood outside did not become sauerkraut at all but was merely spoiled cabbage. This material was rotted to the depth of a foot or more at the top and at the bottom, was raw and contained no appreciable amount of acid. Although such extreme conditions do not prevail in the making of sauerkraut the results show in an exaggerated form some of the effects which may be expected when sauerkraut is made at low temperatures.

FACTORY EXPERIMENTS

Other experiments were conducted in a commercial sauerkraut factory. The cabbage used was the All Seasons variety and had been stored outside for about a month in a well-ventilated hay-covered pile

⁷ PARMELE, H. B., FRED E. B., PETERSON, W. H., MCCONKIE, J. E., and VAUGHN, W. E. RELATION OF TEMPERATURE TO RATE AND TYPE OF FERMENTATION AND TO QUALITY OF COMMERCIAL SAUERKRAUT. Jour. Agr. Research 35: 1021-1038, illus. 1927.

and had a temperature of about 38° F. when brought to the factory for cutting. As it left the cutter it fell through a chute where it was heated by means of a steam jet to the particular temperature desired. The plan followed was to fill three pairs of vats with cabbage at approximately 42°, 60°, and 70°, respectively. Each pair of vats was filled simultaneously so as to have the same grade of cabbage in both. Of the six vats used in the experiment Nos. 2, 6, 5, and 7 were filled the same day with 9 tons of cabbage and Nos. 3 and 9 were filled a day later with 6 tons.

Three copper-constantan thermocouples were put into each vat; one 2 feet from the bottom and the same distance from the side of the vat, another in the center, and the third 2 feet from the top and a like distance from the outside of the vat, but opposite the bottom thermocouple. The cold junction of the thermocouples was kept in ice water in a Dewar flask and the temperature of the junction in the vat read on a Leeds-Northrup potentiometer graduated directly in degrees Fahrenheit.

Another method of obtaining temperatures was used with four of the vats. A bamboo pole, the intersections of which had been bored out, was placed in the middle of the vat at the time of filling. In this tube were suspended thermometers at heights of 2 feet and 4 feet from the bottom. To prevent a change in the reading while the thermometer was being withdrawn and read the lower end was inclosed in a small tube filled with water.

In order to obtain samples of sauerkraut juice small Büchner funnels were attached to thick-walled rubber tubes and were placed in the vats near the top and bottom thermocouples. The sample was drawn into a receiving bottle by means of a hand-operated suction pump. The first portion of the juice was discarded to insure that the sample used for analysis was obtained from the vat and was not juice that had been standing in the tube. Titratable acidity, number of bacteria, and time of methylene-blue reduction were determined on each sample. The methods used for these determinations, and also for the analysis of the sauerkraut, have been described in a previous publication.⁸

TABLE 2.—*Temperature of sauerkraut in factory vats as determined by thermometers at various times during the fermentation*

Age of sauerkraut (days)	Temperature of factory (° F.)	Temperature (° F.) in—							
		Vat 2		Vat 6		Vat 3		Vat 9	
		Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
3.....	45	43	41	43	41	60	54	57	59
4.....	48	42	45	42	43	60	54	62	62
6.....	56	44	46	42	45	62	58	62	63
7.....	60	44	48	43	45	64	59	64	63
9.....	50	45	48	44	46	63	58	64	64
10.....	38	45	48	46	46	62	57	64	65
14.....	54	48	50	50	50	59	54	-----	-----
17.....	55	50	53	52	54	60	57	-----	-----
23.....	57	52	53	53	54	61	59	-----	-----
31.....	52	53	50	52	52	60	57	-----	-----
35.....	55	52	51	52	51	56	53	-----	-----

⁸ PARMELE, H. B., FRED, E. B., PETERSON, W. H., McCONKIE, J. E., and VAUGHN, W. E. Op. cit.

The results of the observations and the analyses are recorded in the accompanying illustrations and tables. The temperatures obtained by means of thermocouples are given in Figures 1 to 3 and those taken with thermometers are recorded in Table 2. The results in most cases do not differ by more than 1° F. Part of this difference is due to the fact that the paired thermometer and thermocouple were a foot or more apart. Unfortunately, because of a change in operation, the last five readings of the thermocouples were erroneous and had to be discarded.

FERMENTATION AT HIGH TEMPERATURES (67° TO 75° F.)

The first sign of fermentation was the evolution of gas. A thick layer of foam formed on the surface of the vat during the first night.

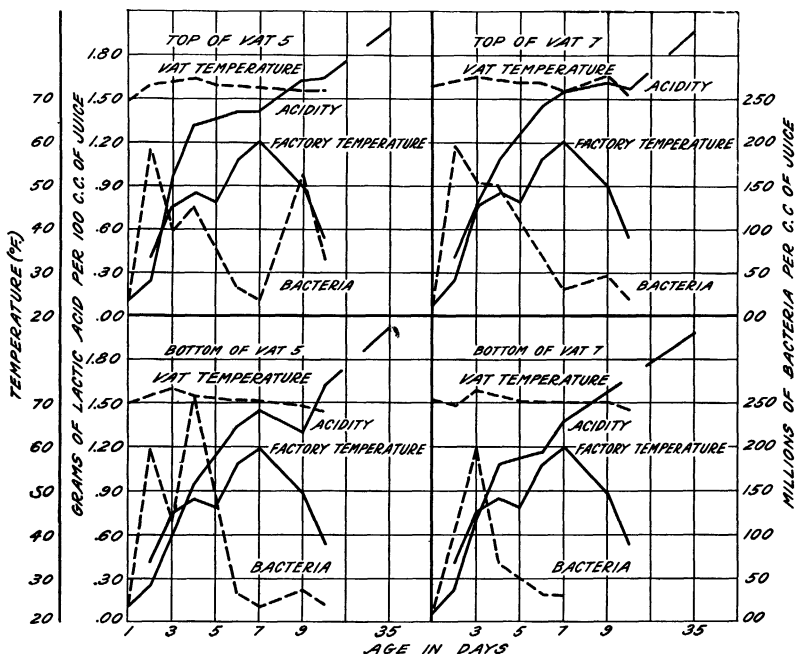


FIGURE 1.—Temperature, acidity, and number of bacteria in vats 5 and 7 at various times during fermentation of sauerkraut

This did not occur on the vats fermented at a medium temperature until after three days and did not occur at all on the vats fermented at low temperatures.

Figure 1 shows that in general the temperature in vats 5 and 7 rose steadily from the first day to the third or fourth day. This rise in temperature can not be attributed to conduction of heat into the vat from the outside, for the vats were approximately 26° F. above factory temperature at the time they were filled. The production of heat must be caused either by plant-cell respiration or by bacterial activity. The latter was perhaps the most important cause, since the rise in temperature coincided with the time at which the bacteria were present in greatest numbers.

The number of bacteria reached a maximum about the second or third day, which was the time when the acidity began to increase rapidly. This increase was greatest during the third and fourth days. As the acid accumulated the number of bacteria decreased. The type of bacteria also changed after the third day. During the first two or three days coccus forms and short rods predominated, but after three days these gave way to large rods, which persisted throughout the remainder of the fermentation.

FERMENTATION AT MEDIUM TEMPERATURES (57° TO 64° F.)

On the first day the temperature in vats 3 and 9 (fig. 2) fell below the initial temperature of the vat. This was probably due to inequalities

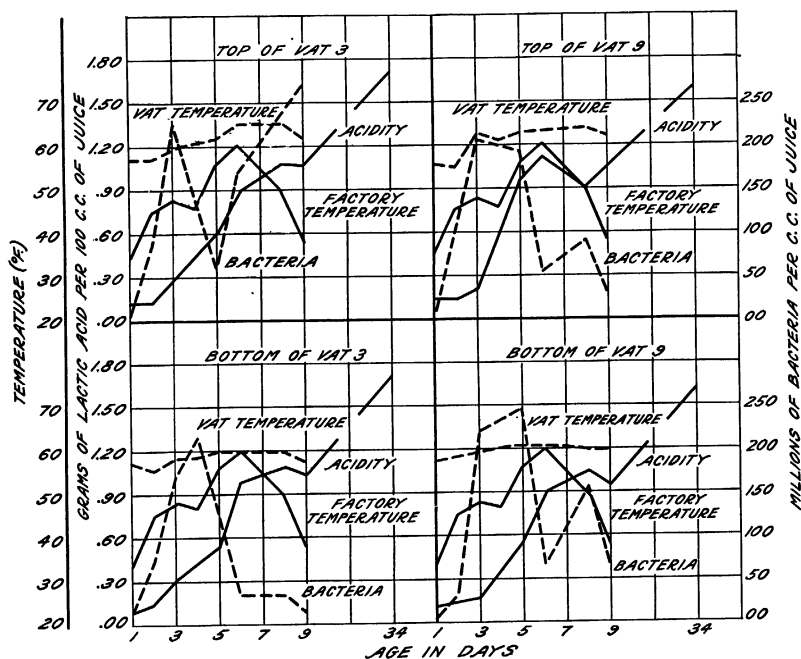


FIGURE 2.—Temperature, acidity, and number of bacteria in vats 3 and 9 at various times during fermentation of sauerkraut

in the temperature of the cabbage in the vicinity of the thermocouple. The temperature began to rise on the second day and continued to do so for five days after which it remained constant until the eighth day. This rise in temperature may be taken as further evidence of the bacterial origin of the heat developed, for it occurred coincidentally with the rise in acidity and the increase in the number of bacteria. If the formation of heat was due to plant-cell respiration the temperature would have risen from the start and would not have been delayed until the second day.

FERMENTATION AT LOW TEMPERATURES (40° TO 46° F.)

The outstanding facts shown by Figure 3 are that at the low temperature of vats 2 and 6, no appreciable action took place. The gradual rise in temperature was probably the result of heat taken up from the

atmosphere. Acid production was low and the numbers of bacteria were small throughout the fermentation. These results are in agreement with those of experiments previously reported on the production of sauerkraut at low temperatures.⁹

CHANGES IN TIME OF METHYLENE-BLUE REDUCTION

The time of methylene-blue reduction may be used as a rough measure of bacterial activity, activity being inversely proportional to the time of reduction, at least approximately. In Table 3 are recorded the changes in the time of methylene-blue reduction of the juice from each of the vats. A comparison of these data with those in

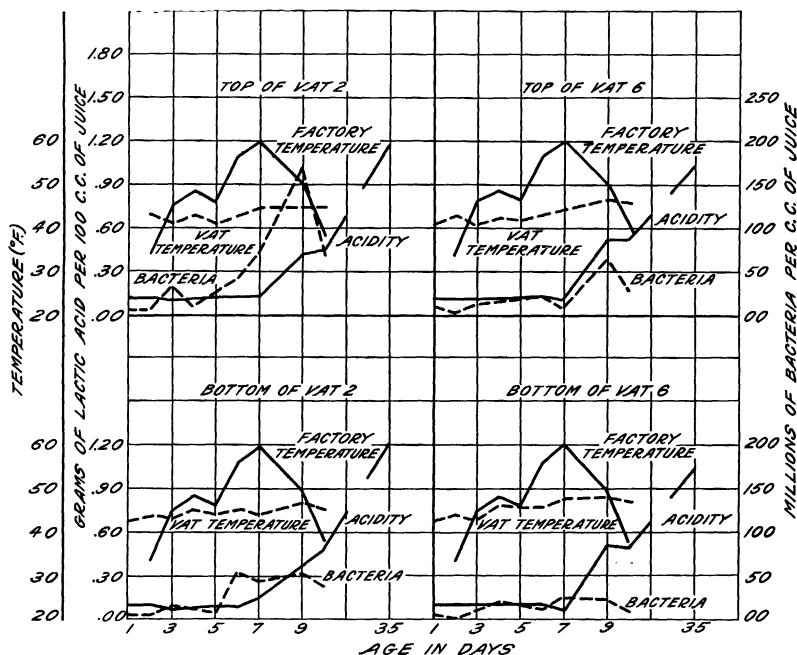


FIGURE 3.—Temperature, acidity, and number of bacteria in vats 2 and 6 at various times during fermentation of sauerkraut

the illustrations shows that the time of reduction fell from a maximum of over 2 hours at the beginning of the fermentation to a minimum of 15 minutes at the end of 3 to 10 days. The minimum time was reached first by those vats which had the highest initial temperature, i. e., the vats in which fermentation was most active.

COMPOSITION AND QUALITY OF THE SAUERKRAUT

The vats at high and medium temperatures were opened at the end of 35 days. The low-temperature vats contained so little acid at this time that they were left to ferment and were first opened at the end of 158 days. Samples were taken from the top, the center, and the bottom of each vat. Table 4 gives the results of the analysis and grading.

⁹ PRIEM, L. A., PETERSON, W. H., and FRED, E. B. STUDIES OF COMMERCIAL SAUERKRAUT WITH SPECIAL REFERENCE TO CHANGES IN THE BACTERIAL FLORA DURING FERMENTATION AT LOW TEMPERATURES. *Jour. Agr. Research* 34: 79-95, illus. 1927.

TABLE 3.—*Changes in time of reduction of methylene blue by sauerkraut juice from vats kept at different temperatures during fermentation*

Age of sauerkraut (days)	Time of reduction in minutes for juice from—											
	Vat 2, 42° F. ^a		Vat 6, 42° F. ^a		Vat 3, 57° F. ^a		Vat 9, 57° F. ^a		Vat 5, 70° F. ^a		Vat 7 70° F. ^a	
	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top
1-----	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
2-----	(b)	(b)	(b)	(b)	105	(b)	(b)	(b)	80	80	90	90
3-----	(b)	(b)	(b)	(b)	15	15	15	15	30	30	15	15
4-----	(b)	(b)	(b)	(b)					15	15	15	15
5-----					15	15	15	15				
6-----	105	(b)	(b)	(b)	15	15	15	15	105	15	15	15
7-----	(b)	(b)	(b)	(b)					15	15	15	15
8-----					15	15	15	15				
9-----	60	60	120	90	90	45	45	45	30	30		15
10-----	15	15	15	90					45	45		60

^a Initial temperature of fermentation.^b Not reduced in two hours.TABLE 4.—*Age, quality, and composition of sauerkraut from experimental vats kept at various fermentation temperatures*

Vat and initial temperature	Age	Mois- ture	Acetic acid	Lactic acid	Ethyl alcohol	Reduc- ing sugars as glucose	Quality of sauerkraut
	<i>Days</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	
Vat 2, 42° F.-----	158	90.5	0.249	1.406	0.282	0.15	Poor.
Vat 6, 42° F.-----	158	89.5	.420	1.576	.326	.12	Do.
Vat 3, 57° F.-----	34	90.2	.371	1.442	.281	.12	Excellent.
Vat 9, 57° F.-----	34	91.9	.332	1.462	.259	.11	Good.
Vat 5, 70° F.-----	35	92.1	.408	1.503	.331	.12	Fair.
Vat 7, 70° F.-----	35	90.6	.420	1.513	.331	.15	Do.

The quality of the sauerkraut which was produced at the highest temperature was only fair judged from the standpoint of flavor, color, and texture. High temperature undoubtedly favors the production of sauerkraut of soft texture and pink color, for numerous soft and pink portions of sauerkraut were found in both vats. It has also been demonstrated in the laboratory that fermentations conducted at high temperatures tend to produce pink sauerkraut. The finest grade of sauerkraut was obtained from the vats kept at intermediate temperatures. The sauerkraut from these vats was white and crisp throughout. The cabbage fermented at the lowest temperature produced sauerkraut that was poor in quality, and possessed a bitter taste, poor texture, and a dark color.

The sauerkraut from the different vats showed no essential difference in percentage content of fermentation products. The quality of sauerkraut depends upon something other than mere acidity. While a proper degree of acidity may be taken as the first requisite, there are other products, as yet not measured, which distinguish a sauerkraut of good flavor from one of poor flavor.

SUMMARY

The quality of sauerkraut was found to depend very largely upon the temperature at which fermentation was carried out, the most favorable temperature for fermentation was between 60° and 65° F.

High temperatures favored the production of soft and pink sauerkraut.

A rise of 3° to 5° F. occurred during the first eight days in fermentation vats kept at temperatures above that of the surrounding air. This rise in temperature was coincident with the greatest activity of the bacteria and is believed to have been caused by bacterial action.